

PRELIMINARY REPORT ON
THE WATER RESOURCES OF
THE LAHAINA DISTRICT
MAUI

Circular C51

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with
Division of Water and Land Development
DEPARTMENT OF LAND AND NATURAL RESOURCES
State of Hawaii

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By George Yamanaga and C.J. Huxel

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HONOLULU, HAWAII
February 1969

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SUMMARY

The Lahaina District, approximately 96 square miles in area, consists of the western part of the West Maui volcanic dome. Numerous intersecting dikes in the central part of the dome, where rainfall is high, impound a large high-level ground-water body, oval-shaped in plan.

All perennial streams in the Lahaina District derive their dry-weather flow (base flow) from this high-level water body, having cut down into the zone of saturation and serving as open drains. In the aggregate, low flow of streams in the District exceeds 25 mgd (million gallons per day).

Basal ground water occurs in a peripheral belt surrounding the area of high-level water. Pumpage from the basal-water body averages about 50 mgd. The absence of extensive caprock along the shore allows hydraulic continuity and free circulation between sea water and fresh water, and the fresh-water lens is thin near the shore. Heavy, concentrated pumping from wells and shafts, even as much as 3,000 feet inland, results in large, though usually temporary, increases in salinity. In general, fresher water is found farther inland, nearer the high-level water. Leakage of high-level water through confining boundary dikes is probably a major recharge source for the basal-water body.

The high-level water body appears to be the most promising source that might be tapped if additional domestic water is needed.

INTRODUCTION

Purpose and Scope

This report outlines the occurrence of water in the Lahaina District and summarizes what is known about the quantity and quality of water available for development. It briefly describes the geology, the streams, ground water, and the extent of present development of water. It summarizes information available on streamflow and on discharge and quality of ground water and outlines information and investigations that are needed for more comprehensive appraisal of the water supplies. The report was prepared by the U.S. Geological Survey in cooperation with the Hawaii State Department of Land and Natural Resources, Division of Water and Land Development.

Geographic Setting

The Lahaina District, about 96 square miles in area, consists roughly of the western half of West Maui (fig. 1). The boundary between the Lahaina and the Wailuku Districts runs generally along ridges which roughly delineate rift zones. The highest point in the District is Puu Kukui, 5,788 feet above sea level, on the boundary near the center of the mountain mass.

Valleys in the northern half of the District are generally long and narrow; those in the southern half are shorter and tend to be amphitheater-headed.

Agriculture, especially the cultivation of sugar cane, uses large amounts of water. It has been and will probably remain for sometime the principal industry of the Lahaina District, but recent and planned future developments of tourist and resort facilities indicate that domestic water use will increase considerably.

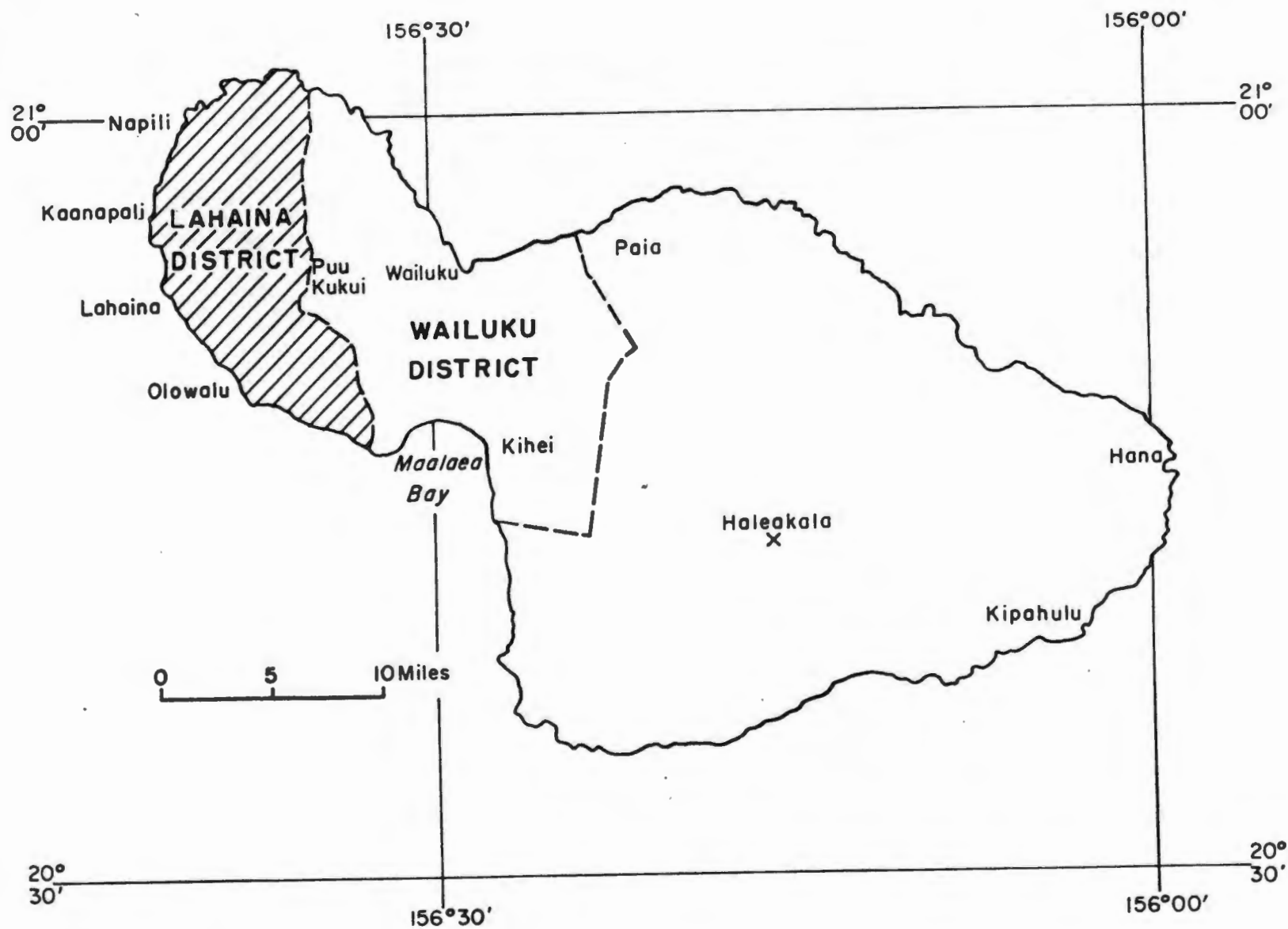


Figure 1. MAP OF MAUI SHOWING LOCATION OF LAHAINA DISTRICT

Previous and Present Investigations

The geology and ground-water resources of West Maui were described in an island-wide study by H.T. Stearns and G.A. Macdonald (1942). Streamflow information has been collected since 1911 and is published by the Geological Survey in annual Water-Supply Papers.

The water-supply systems of the District were described in a report by the Division of Water and Land Development (1963).

The present report is based mainly on these previous reports, other unpublished reports and data, and on records compiled subsequently. Measurements of dry-weather flow of several streams were made during this study.

Acknowledgments

Assistance received during this study is gratefully acknowledged. Information on streamflow diversions and ground-water discharge on Pioneer Mill Co.'s land was provided by John W. Siemer, Robert T. Vorfeld, Harvey D. Tripple, and James H. Greig. Information on stream diversions maintained by the Honolua division of Maui Pineapple Co. was provided by J.R. Stegmuller and S. Takayama. Unpublished material compiled by H.T. Stearns was also made available by Pioneer Mill Co.

RAINFALL

The mean annual rainfall in the Lahaina District ranges from less than 15 inches to more than 400 inches (fig. 2). Precipitation is least along the southern shores and greatest near Puu Kukui.

Annual rainfall at "Kahoma intake" (RG-374), typical of the uplands, and at "Lahaina" (RG-361), typical of the lowlands, is plotted in figure 3. The distance between these stations is less than 4 miles; "Lahaina" is about 30 feet above sea level, "Kahoma intake" about 2,000. The range in annual rainfall at Lahaina is from 3.20 inches to 34.78 inches, a 10-fold variation; the range at Kahoma intake is from 33.41 inches to 154.44 inches, a 5-fold variation.

The variation in rainfall at Kahoma intake and at Lahaina is shown in figure 4, in which maximum, mean, and minimum monthly rainfalls are plotted. June is the driest month. At Lahaina, June rainfall was less than half an inch in 46 of the 47 years, 1919-65; 1.04 inches fell in 1926. No rain fell during June in 29 of these years. A month without rainfall is not unique to June, however, as all months except December have been rainless at times; the December 1922 rainfall totaled 0.02 inch. Frequently no rain has fallen for 2 consecutive months, and there have been 4- and even 5-month periods during which no rain was recorded. From May to November 1953, only 0.01 inch was recorded; 0.12 inch fell in April 1953.

At Kahoma intake monthly rainfall has never been zero; however, minimum monthly rainfall was less than 1 inch for 8 of the 12 months.

Based on figure 2, rainfall in the Lahaina District was computed to average 340 mgd (million gallons per day).

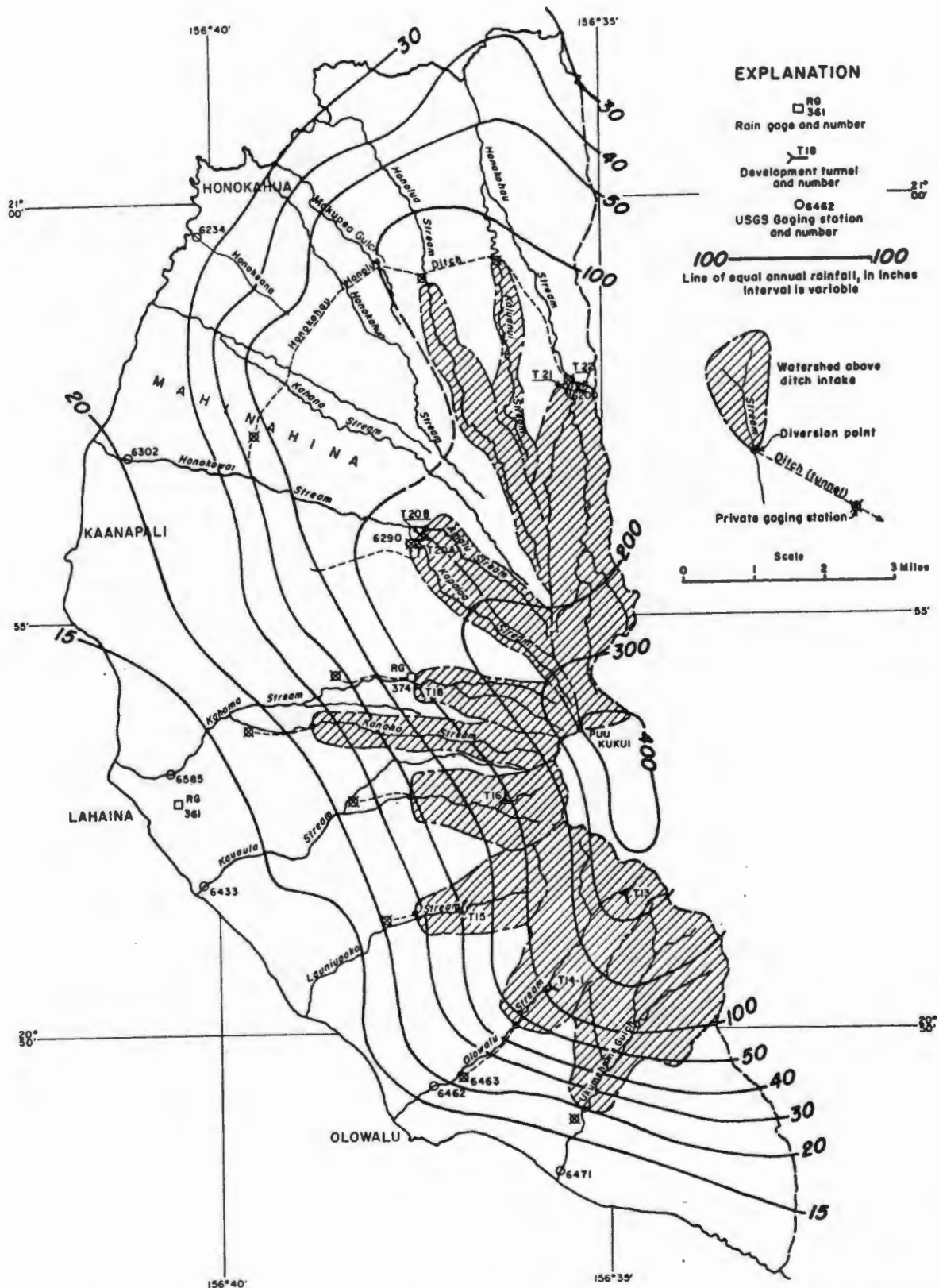


Figure 2. MAP OF WEST MAUI SHOWING DISTRIBUTION OF MEAN ANNUAL RAINFALL AND LOCATION OF SELECTED RAINFALL AND STREAMFLOW STATIONS, TUNNELS, AND DITCHES

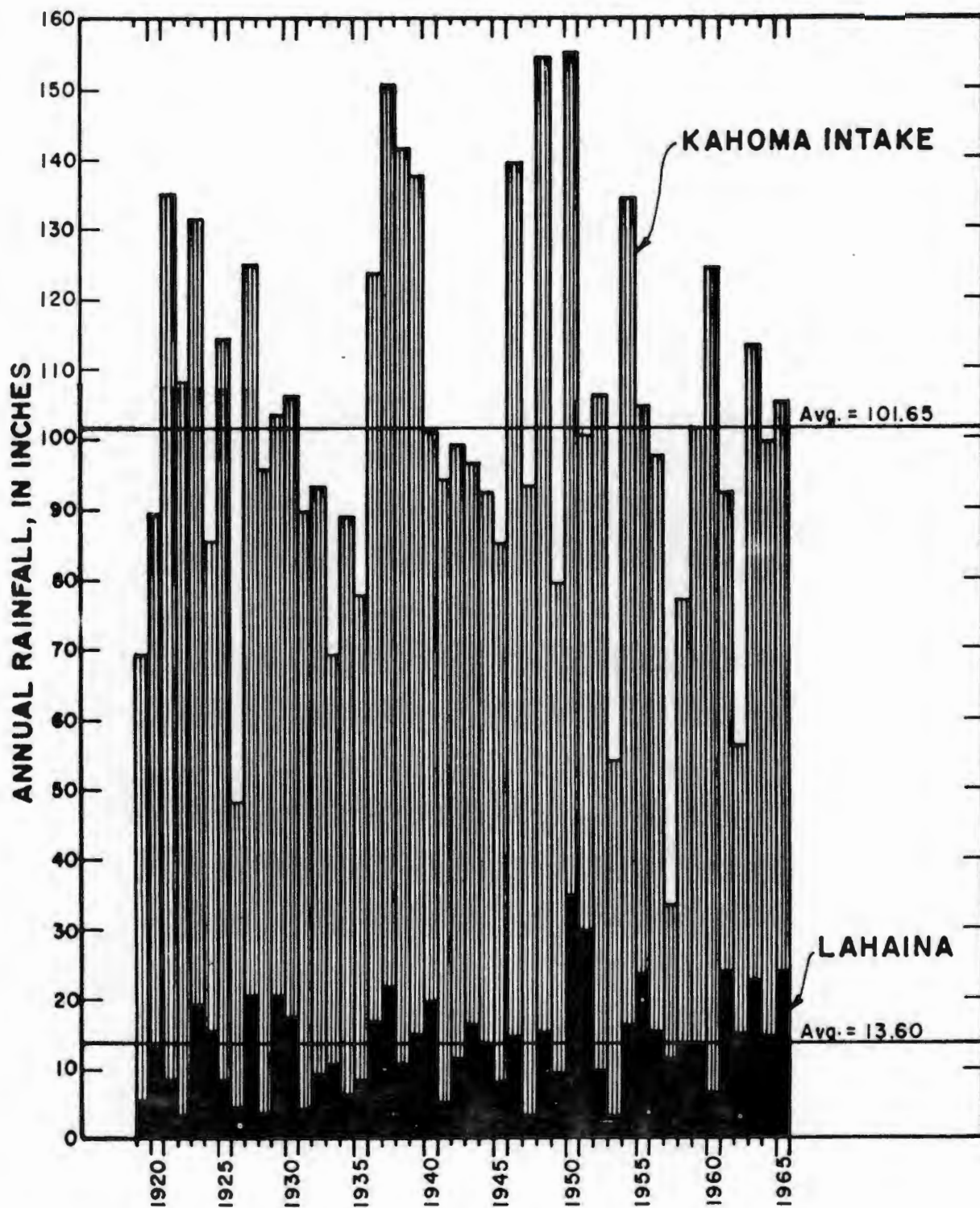


Figure 3. GRAPHS SHOWING VARIATIONS IN RAINFALL AT KAHOMA INTAKE (RG-374) AND AT LAHAINA (RG-361)

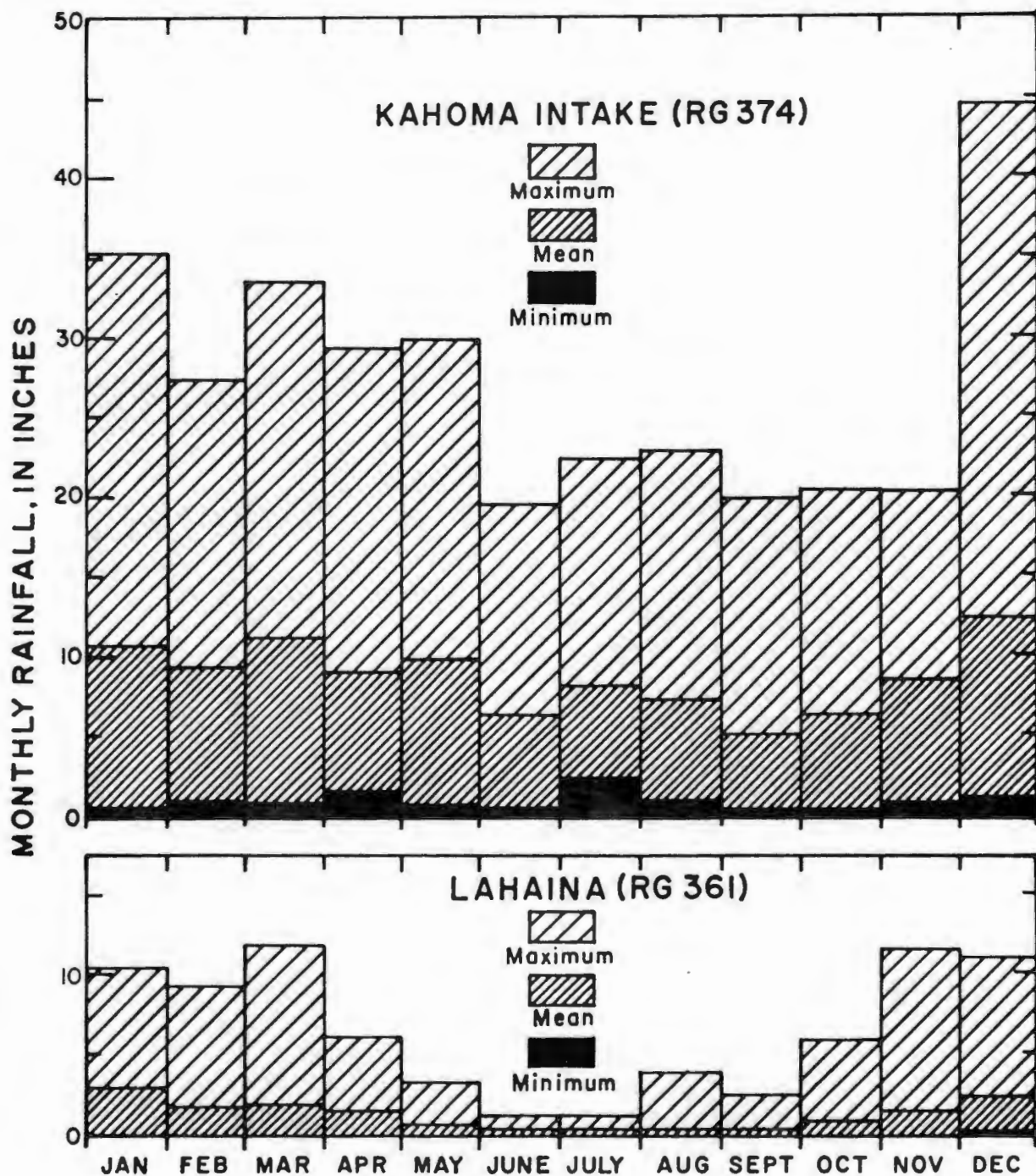


Figure 4. GRAPHS SHOWING MEAN, MAXIMUM, AND MINIMUM MONTHLY RAINFALL AT KAHOMA INTAKE AND AT LAHAINA (Minimum monthly rainfall at Lahaina is zero for all months except December; December minimum is 0.02 inch.)

GEOLOGY

The geology of West Maui is described in detail by Stearns and Macdonald (1942, p. 156-187). The Lahaina District lies on the west side of a deeply dissected dome of volcanic rocks called West Maui Mountain. West Maui Mountain is nearly circular in plan and is asymmetric in profile. The volcanic flows on the east and south sides dip more steeply than those on the north and west sides. The dome has been reduced by erosion from a summit altitude estimated to have been 7,000 feet (Stearns, 1942, p. 156) to 5,788 feet at Puu Kukui. Numerous steep-walled valleys have been cut in the mountain.

Volcanic rocks of West Maui Mountain are lava flows, dikes, and pyroclastic deposits ranging from Pliocene (?) to late Pleistocene or Holocene in age (Davis and Macdonald, in Avias, Jacques, 1956). On the basis of lithology and stratigraphic position, these rocks are differentiated into the Wailuku, Honolua, and Lahaina Volcanic Series. Sedimentary rocks consist of consolidated marine, alluvial, and colluvial deposits of middle and late Pleistocene age and unconsolidated beach and alluvial deposits of Holocene age.

The areal distribution of rocks in the Lahaina District is shown on figure 5, and their lithology and water-bearing characteristics are summarized in table 1.

The great bulk of the rocks making up West Maui Mountain is primitive olivine basalt of the Wailuku Volcanic Series. The Wailuku flows are thin-bedded and scoriaceous in the southern part of the Lahaina area, where they flowed on steep dip slopes, and are characterized by structural features such as interflow clinker beds, scoriaceous zones, lava tubes, and joints. Where they have never been covered by younger volcanic rocks, they are weathered as deep as 100 feet. Individual flows are as thick as 100 feet.

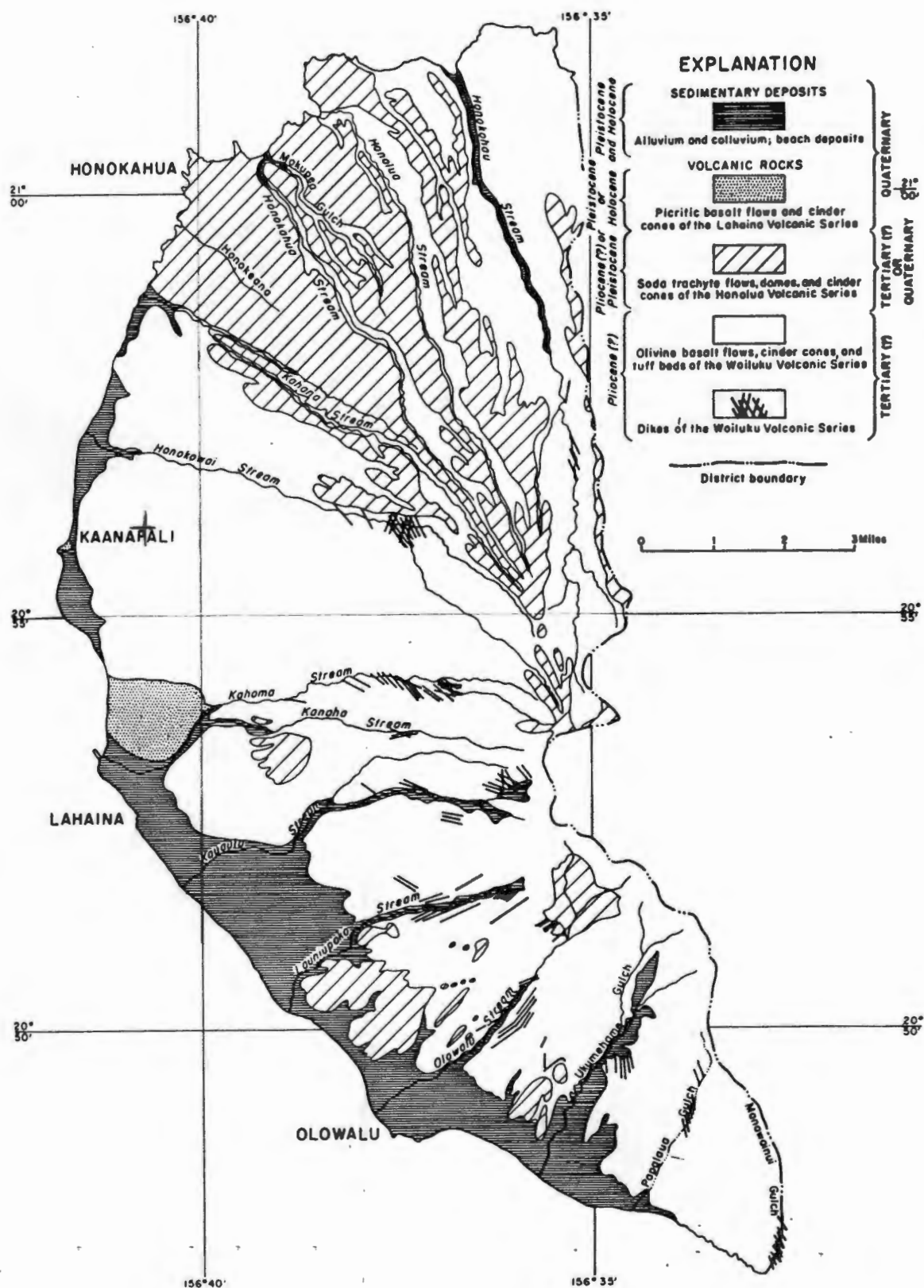


Figure 5. GENERALIZED GEOLOGIC MAP OF LAHAINA DISTRICT

Table 1. GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Geologic unit	Age	Maximum thickness (ft)	Lithology	Water-bearing characteristics	
Sedimentary deposits	Pleistocene and Holocene	200+	Unconsolidated beds of alluvial silt, sand, and gravel in stream valleys; beach sand and gravel near the coast. Consolidated rocks consist of dune sand, weathered alluvial conglomerate and colluvium, and cemented alluvial and marine conglomerate.	Consolidated alluvial, colluvial, dune, and beach deposits are poorly permeable and unimportant as sources of water supply. They may form a caprock in some areas. Unconsolidated beach deposits may yield large amounts of brackish water to wells; unconsolidated alluvium in perennial stream valleys may yield small amount of fresh water to wells.	
Volcanic deposits	Lahaina Volcanic Series	Pleistocene or Holocene	150+	Lava flows of picritic basalt and nepheline basanite; cinder and spatter cones.	Small in areal extent and unimportant as a source of fresh water.
	Honolua Volcanic Series	Pliocene (?) or Pleistocene	1,000+	Massive lava flows and domes of soda trachyte; cinder cones; dikes.	Lava flows are massive and thick-bedded and are permeable only along interflow clinker zones; of little value as an aquifer.
	Wailuku Volcanic Series	Pliocene (?)	5,500+	Thin-bedded lava flows of primitive olivine basalt; cinder and spatter cones and thin tuff beds; numerous dikes.	Lava flows constitute the main aquifer and are highly permeable. Yields from skimming tunnels as much as 10 mgd. Pyroclastic deposits are not extensive and are unimportant as aquifers. Thin, impermeable tuff beds in several valleys support perched ground-water bodies that supply small high-level springs. Dikes are dense and of low permeability and retard or divert ground-water movement in the lava beds they cut.

The Wailuku basalt is cut by numerous dikes, many of which are exposed in the walls of the major valleys. The dikes range in thickness from a few inches to as much as 35 feet (Stearns, unpublished report). Major north and south dike systems extending from Iao Valley were recognized by Stearns (1942, p. 163), and general north and south rift zones paralleling the dike systems were mapped by him (1942, p. 81). More recent work (Malahoff and Woollard, 1966, p. 275, 296) shows evidence of a major east-west rift zone. Dike trends are shown in figure 5, and the general strikes of the dikes in each major valley are summarized in table 2.

The Wailuku basalt flows are veneered in places by andesite and sodatrachyte of the Honolua Volcanic Series. The Honolua lava flows are much denser and more massive than the underlying Wailuku basalt. They range in thickness from about 50 to 500

Table 2. STRIKE OF DIKES IN MAJOR VALLEYS
OF THE LAHAINA DISTRICT

Valley	Direction of strike	Relation of dikes to each other
Honokohau	N	Parallel
Honolua	No dikes	
Honokahua	No dikes	
Kahana	W to N	Intersecting
Honokowai	NNW with NNE to ENE	"
Kahoma	NW	"
Kanaha	NW	"
Kauaula	NW with NNW to WNW	"
Launiupoko	WSW to SW	"
Olowalu	SW to S	"
Ukumehame	S to SSE	Parallel
Papalaua	SSE	"
Manawainui	SSE	"

feet and are more resistant to erosion and form a protective caprock over the older and weaker basalt. Stearns (1942, p. 174) found that the Honolua lava flows were originally more extensive than at present and probably reached their greatest thickness on the northern flank of West Maui Mountain.

Sedimentary deposits occur in the bottoms of major valleys and along much of the coast. Consolidated sedimentary rocks consist of older alluvial conglomerate, talus breccia, calcareous dune sand and marine conglomerate. The maximum thickness of these rocks in the Lahaina District probably exceeds 200 feet. Unconsolidated deposits of younger alluvium and beach sediments may be found along the coast and in some of the major valleys.

Water-Bearing Properties of Rocks

The principal water-bearing rocks of West Maui are basalt of the Wailuku Volcanic Series. Areal extent of these basaltic rocks, in relation to rocks of the younger Honolua and Lahaina Volcanic Series and to sedimentary rocks, is shown in figure 5. The Wailuku basalt is described as being highly permeable because of its slaggy, tubular, clinkery character. Stearns (1942, p. 162) stated that it is probably more permeable than basalt of the Koolau Volcanic Series of Oahu.

The vertical dikes of dense basalt, which intrude the Wailuku flows, form fairly impermeable barriers, directing ground water to move generally parallel to the major dike trends. Some water moves by leakage through joints and cracks in the dikes. Where dikes intersect, they form compartments within which water is impounded.

The Honolua lava flows have relatively low permeability and are generally too discontinuous to function as aquifers. The deposits of the Lahaina Volcanic Series are the youngest volcanic rocks in the area and are not extensive enough to be important as water-bearing formations. However, the Puu Laina cinder cone northeast of Lahaina is important in the following way--its crater is used as a reservoir to store irrigation

water. The crater leaks freely and thereby causes local freshening of the basal ground-water lens in that vicinity.

Pyroclastic deposits are generally unimportant as aquifers because they are of small areal extent. Locally, however, tuff layers interbedded with lava flows may perch small amounts of water.

The consolidated sedimentary rocks are unimportant as aquifers because they are poorly permeable and are generally above the basal-water lens. Unconsolidated alluvial deposits in perennial stream valleys yield small quantities of fresh water to wells, but alluvial and beach deposits near the coast yield moderate to large amounts of brackish water.

WATER RESOURCES

Of the average 340 mgd of rain that falls in the District, about 250 mgd falls in the area of high-level water. 170 mgd of this falls in watersheds feeding ditch intakes. Ditches divert an average of about 57 mgd of water from streams for domestic use and for irrigation of cane.

Ground-water pumpage from the basal lens in the District is about 50 mgd.

Ground Water

Ground water occurs in the Lahaina District mainly as high-level dike-held water within the upper mountainous area and as basal water in areas bordering the high-level water body.

The high-level water body is recharged principally from direct infiltration of rainfall and from infiltration of streamflow. Discharge consists of flow from springs, tunnels, and seeps, which maintains the base flow of streams, and leakage through the dike system to the basal-water body.

The basal-water reservoir is recharged by infiltration of rainfall and streamflow, deep seepage of applied irrigation water, and leakage from the high-level water body. It is discharged by coastal springs, diffuse underflow to sea and withdrawal by pumping.

High-Level Ground Water. High-level ground water is confined far above sea level in compartments of lava bounded by intersecting dikes. Because of a radial dike pattern characterizing West Maui Mountain, the high-level ground water occurs in an oval-shaped area underlying the central part of the mountain (fig. 6). The inferred boundary between the high-level and the basal ground-water areas is drawn along the edge of the dike zone in most places.

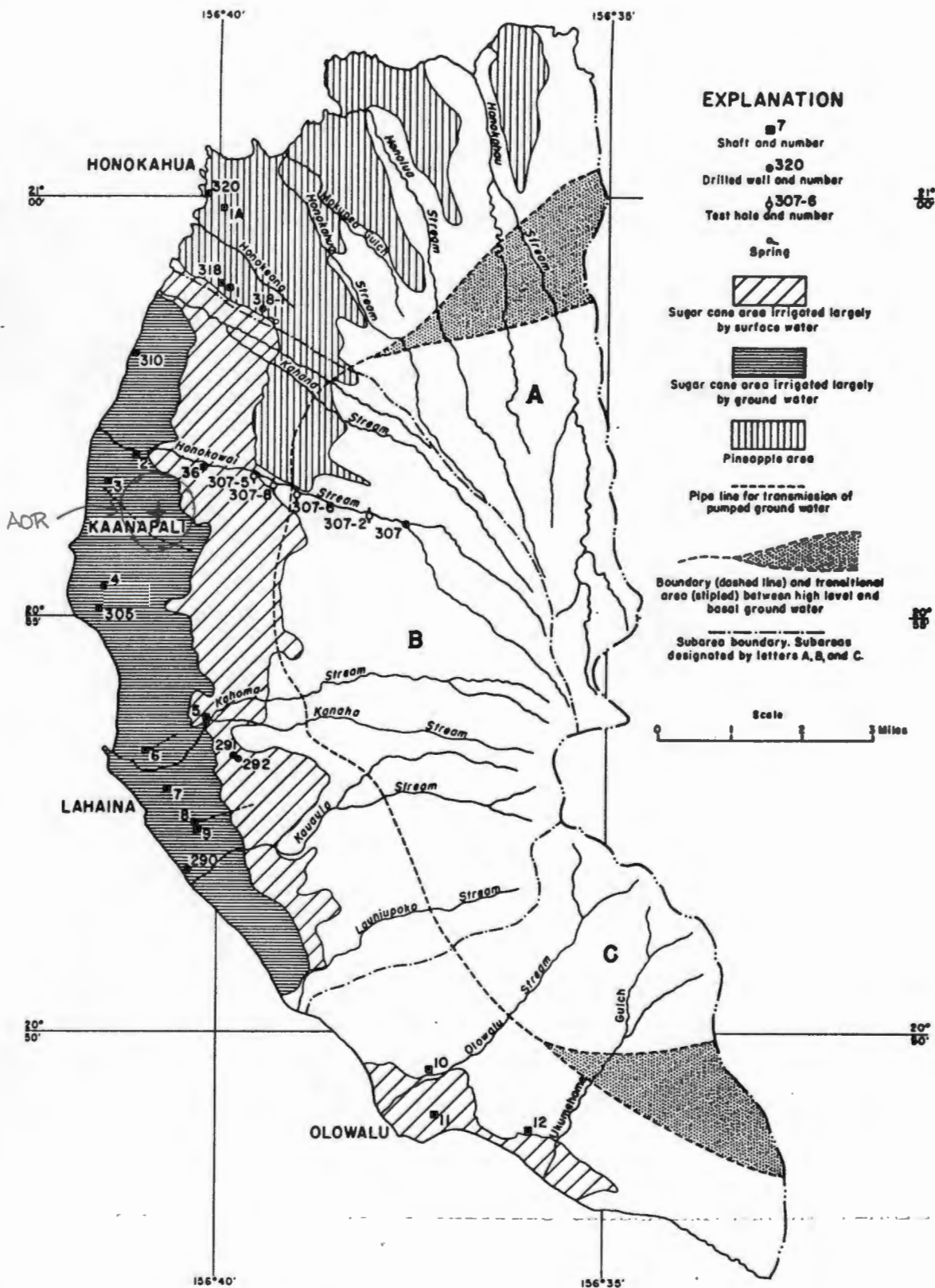


Figure 6. MAP SHOWING HYDROLOGIC SUBAREAS, WELLS, SHAFTS, TEST HOLES, PIPELINES, AND CULTIVATED AREAS

The boundary is very sharp in some places and is indicated by an abrupt change in head between the high-level and basal-water areas. For example, in Honokowai Valley, between wells 307-6 and 307-8 (fig. 6), 2,000 feet apart, there is a 500-foot difference in head. In such places, dikes intersect to form compartments, and water moves under high head through jointed or fractured dike walls to eventually reach the basal-water reservoir. In other places, where dikes are more or less parallel, ground water moves parallel to dominant dike trends.

The head difference required to move the water through the lava flows is small, and the transition between high-level and basal ground water is not sharp. This type of transition probably prevails in the southern part of the Lahaina District from Ukumehame Valley to the District boundary and in the northern part of the area from Honolulu Valley to Honokohau Valley (fig. 6).

Heavy rainfall in the uplands of West Maui recharges the high-level reservoir. High-level water discharges from springs and seeps emanating from dikes breached by stream valleys and by underflow either through or along the dikes. The chemical quality of high-level water is comparable to that of rainwater.

Basal Water. Basal water occurs in areas bordering the high-level water area as a thin lens of fresh water floating on sea water. In most places, the top of the lens ranges from a few inches to a few feet above sea level. In some areas, such as the transitional areas between high-level and basal water (fig. 6), it may be as much as a few tens of feet above sea level.

The thickness of the fresh-water lens may be determined by measuring the chloride concentration at regular depth intervals below the top of the lens. Measurements made in 1954 (Stearns, unpublished report to American Factors, Ltd.) near well 7 near Lahaina (fig. 6) show an abrupt increase in chloride concentration, 2,500 mg/l (milligrams per liter, equivalent to parts per

million, ppm) to 13,000 mg/l (ppm), between 36 and 46 feet below sea level. Between 46 feet and the bottom of the well, the chloride concentration increased to 19,000 mg/l (ppm). The data are summarized in table 3.

The chloride concentration of water from wells in the basal lens ranges from 21 mg/l (ppm) (well 307-8) to 15,000 mg/l (ppm) (well 305) (table 4). The sample from well 307-8 is a static sample; all other samples listed in the table are from pumping wells. The general distribution of chloride concentration in water from wells is shown in figure 7. Chloride concentrations are highest near the coast in areas of heavy pumping and presumably in areas where there is free circulation and effective hydraulic continuity between sea water and fresh water because of high permeability of the aquifer and the absence of caprock. Alluvial and coralline deposits along the coast yield water of

Table 3. DEPTH PROFILE OF WELL K-1, PIONEER MILL*

Altitude of sample (ft above or below msl)	Chloride concentration (milligrams per liter)**
+ 2.22 (static)	997
- 6.0	997
-16.0	1,014
-26	790
-36	2,490
-46	13,340
-56	14,590
-66	15,960
-76	18,000
-86 (bottom of well)	19,320

*Quoted in Stearns, H.T., Unpublished report to American Factors, Ltd.; measurement by S. Cheatham, September 1954.

**Milligrams per liter (mg/l) equivalent to parts per million (ppm).

Table 4. WELLS DRILLED SINCE 1940

Well No.	Owner or name	Year drilled	Use	Dia-meter (in)	Depth (ft)	Casing length (ft)	Altitude (ft above msl)	Date	Water levels (ft above msl)	Chloride		Drawdown/Yield (ft) (gpm)	Temperature °F °C	
										Concen-tration (mg/l)	Pumping rate (gpm)			
290	P. Shaw	1956	N	6	55	20	10	3-9-56	--	3,140		-- /150	--	
291	DOWALD* (Wai Puha)	1962	PS	8	497	476	440.75	5-8-62	2.6	118	375	2.60/325	70	21
								2-17-67	--	180	325			
292		1963	PS	12	520 498	482	441	2-11-63	2.00	240	600	0.60/600	69	21
								3-4-63	1.51	140	600			
								2-17-67		165	300			
305	Janas Corp.	1964	**	12	94	74	3.2	8-14-64	1.2			1.1/900	76	24
								9-22-64	0.51	15,000	600			
307	Pioneer Mill Co., Ltd.	1965	PS	12	165	--	1,450	2-21-67	1,427.5	--		29.5/945	--	
310	C.H. Durksen	1956	D	6	53	20	15	6-9-58	--	942		-- / --	--	
318	DOWALD*	1964	PS	8	284 274	284	257	6-29-64	2.69		500	1.17/500	69.5	21
								7-1-64		318				
								7-6-64	2.60		500			
								7-7-64		352				
318-1	"	1966	PS		526 574 521	--	493			180		20/215	--	
										550		1.7/500		
										170		20/100		
320	D. Fleming	1956	N	6	60	5	15	3-9-56	--	869		-- / 50		
307-2	Pioneer Mill	1965	T	--	--	--	1,350	--	--	--		-- / --		
307-7	"	1965	T	3/4	314	--	1,169	2-21-67	910.38	--		-- / --		
307-6	"	1965	T	3/4	252	--	776	12-23-66	561.20			-- / --		
								2-20-67	574.42	--				
307-8	"	1965	T	1	671	--	651	11-15-66	4.26					
								2-13-67	7.24	21#				
307-5	"	1965	T	3/4	580	--	560	10-24-66	2.65			-- / --		
								2-13-67		46#				
								2-19-67	5.74					

* Division of Water and Land Development.

**Water used to fill lagoon.

#Static sample.

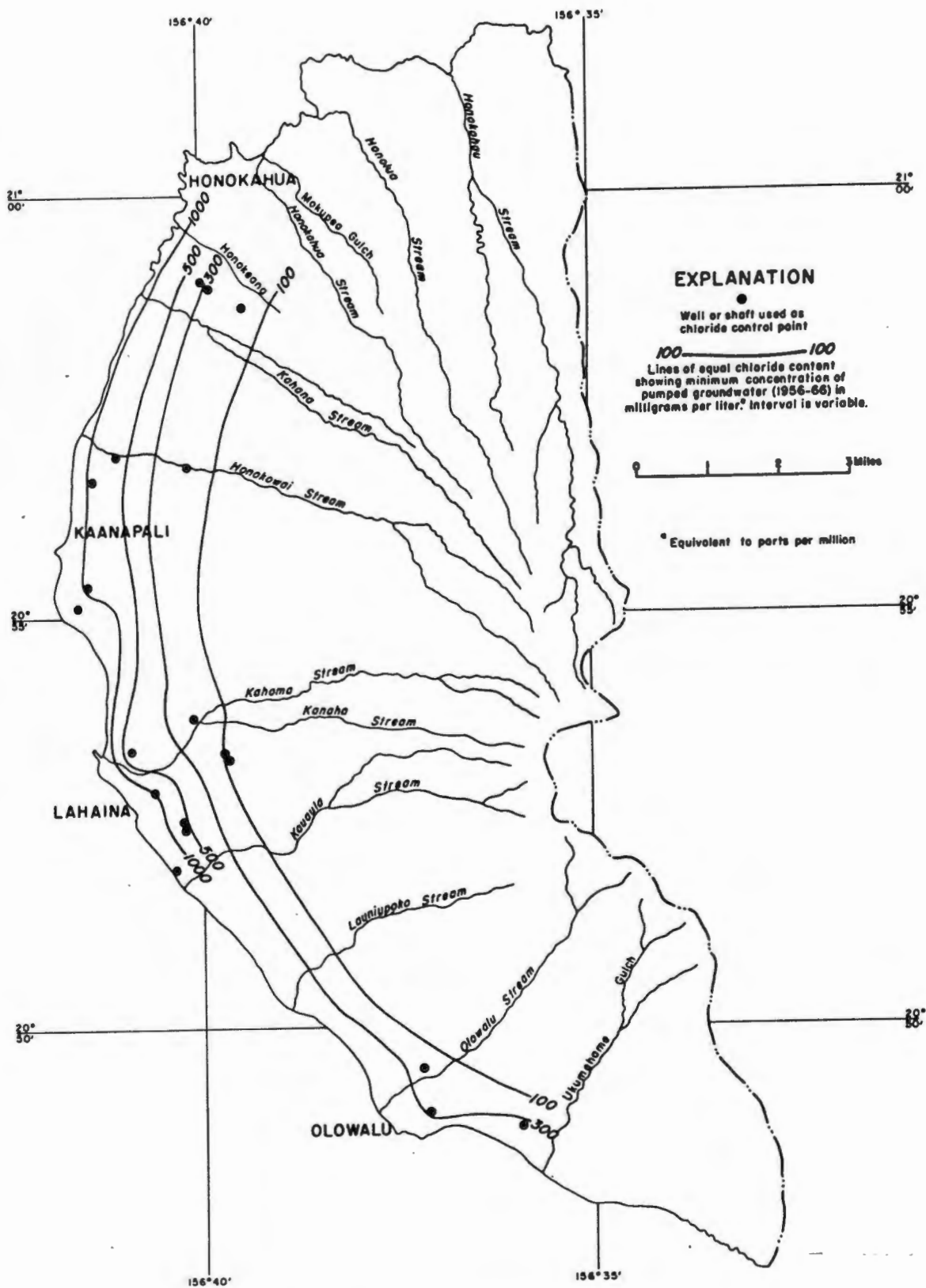


Figure 7. MAP SHOWING LINES OF EQUAL CHLORIDE CONTENT IN LAHAINA AREA, 1963

particularly high chloride concentration probably because of tidal effects, which cause a high degree of mixing between sea water and fresh water.

Streamflow

Streams flow in all of the more deeply eroded valleys even during dry weather. The dry-weather flow is maintained by discharge from the high-level ground-water body resulting from breaching of confining dikes by deep stream cutting. However, mainly because of ditch diversions, only Honokohau Stream flows perennially to sea. In Honokohau Valley, all water that rises from springs downstream of the diversion point is allowed to flow downstream to satisfy water rights of farmers in the lower section of the valley.

Extensive diversion facilities are maintained by Maui Pineapple Co. and Pioneer Mill Co. Maui Pineapple Co. delivers about 25 mgd to Pioneer Mill Co. at Mahinahina through its Honokohau (Honolua) ditch. Water in this ditch is collected from Honokohau Stream, from development tunnels in Honokohau Valley, and from Kaluanui (local name) and Honolua Streams.

In addition to the 25 mgd received from Honokohau ditch, Pioneer Mill Co. obtains about 29 mgd of stream water from diversions on other streams (see table 5).

Stream Gaging in the Lahaina District

The Geological Survey presently operates recording gages on three streams in the District--Honokohau (6200), Kahoma (6385) and Olowalu (6462). (See fig. 2.) In addition, crest-stage gages are maintained on Honokeana Gulch (6234), Honokowai Stream (6302), Kauaula Stream (6433), and Ukumehame Gulch (6471).

Pioneer Mill Co. operates recording gages on all its major diversions, as well as on a water-development tunnel (T-20A), in Kapaloa Valley. Flows, as measured in the ditches, represent practically all the low and medium flows of the streams from which water is diverted. Records obtained by Pioneer Mill Co.

Table 5. MAJOR STREAMS IN LAHAINA DISTRICT

Stream	Altitudes of diversion (ft)	Drainage area above intake (sq mi)	Rainfall on drainage area (mgd)	Discharge (mgd)		
				Average flow (estimated)	Average diverted	Minimum
Honokohau	870	4.3	49.8	30	25*	5.6
Honolua	870	1.8	11.8	5	2.8*	0
Honokowai				8	5.7	2.3
Amalu	1,580	1.0	8.6			
Kapaloa	1,550	1.1	12.2			
Kahoma	1,930	1.5	14.4	7	5.2	2
Kanaha	1,140	1.6	7.5	5	2.5	1
Kauaula	1,530	1.9	9.1	7	5.7	5.2
Launiupoko	1,280	1.2	3.7	1	.7	.5
Olowalu	540	3.4	32.0	6	5	3
Ukumehame	240	4.1	19.2	6	4.3	3.1
Total (rounded)		22	168	75	57	23

*Some water either lost by seepage in Honokohau ditch or diverted for use between Honokohau and delivery point at Mahinahina weir, where average is 25 mgd.

from their Honokowai and Olowalu ditch stations are furnished to the Geological Survey for publication in its annual releases.

Maui Pineapple Co. maintains recording gages on Honokohau ditch at its intake at Honokohau Valley, as well as at the delivery point at Mahinahina. Recorders also measure feeder-ditch flow from intakes at Kaluanui and Honolua Streams.

During the past years, the Geological Survey has operated gaging stations on some other sites in the District. Records for these sites were published in Water-Supply Papers and were summarized and published in Water-Supply Paper 1319 (U.S. Geological Survey, 1961).

Streams

Streams in the Lahaina District radiate from the summit of the mountain mass. Those in the northern half of the District are longer, and, with the exception of Honokohau, their valleys are not deeply incised; therefore, their gradients approximate the slope of the land.

The streams in the southern half have formed amphitheater-headed valleys, somewhat similar to Manoa Valley on Oahu.

Honokohau Stream. The Honokohau drainage, the longest in West Maui, begins at Puu Kukui, and the stream flows 9 miles to sea through a long, narrow valley. For about the first mile it slopes gradually (this reach seems to be undergoing piracy by Waihee Stream); it then drops precipitously, 1,400 feet in a mile and a half, and continues more gently on the bottom of a valley, which is as deep as 2,300 feet.

Honokohau Stream is the only one in the Lahaina District that flows perennially to sea. Its flow has been gaged by the Geological Survey since 1913 at a site just above the Honokohau ditch intake. Records to 1965 for this site (6200) show that, from the 4.1 square miles above the station, flow has averaged 26.0 mgd and has ranged from 5.4 to 2,420 mgd. Flow-duration curves for the period 1923-65, for 1945 (a dry year), and for 1937-38 (a wet period), are shown in figure 8. Recurrence

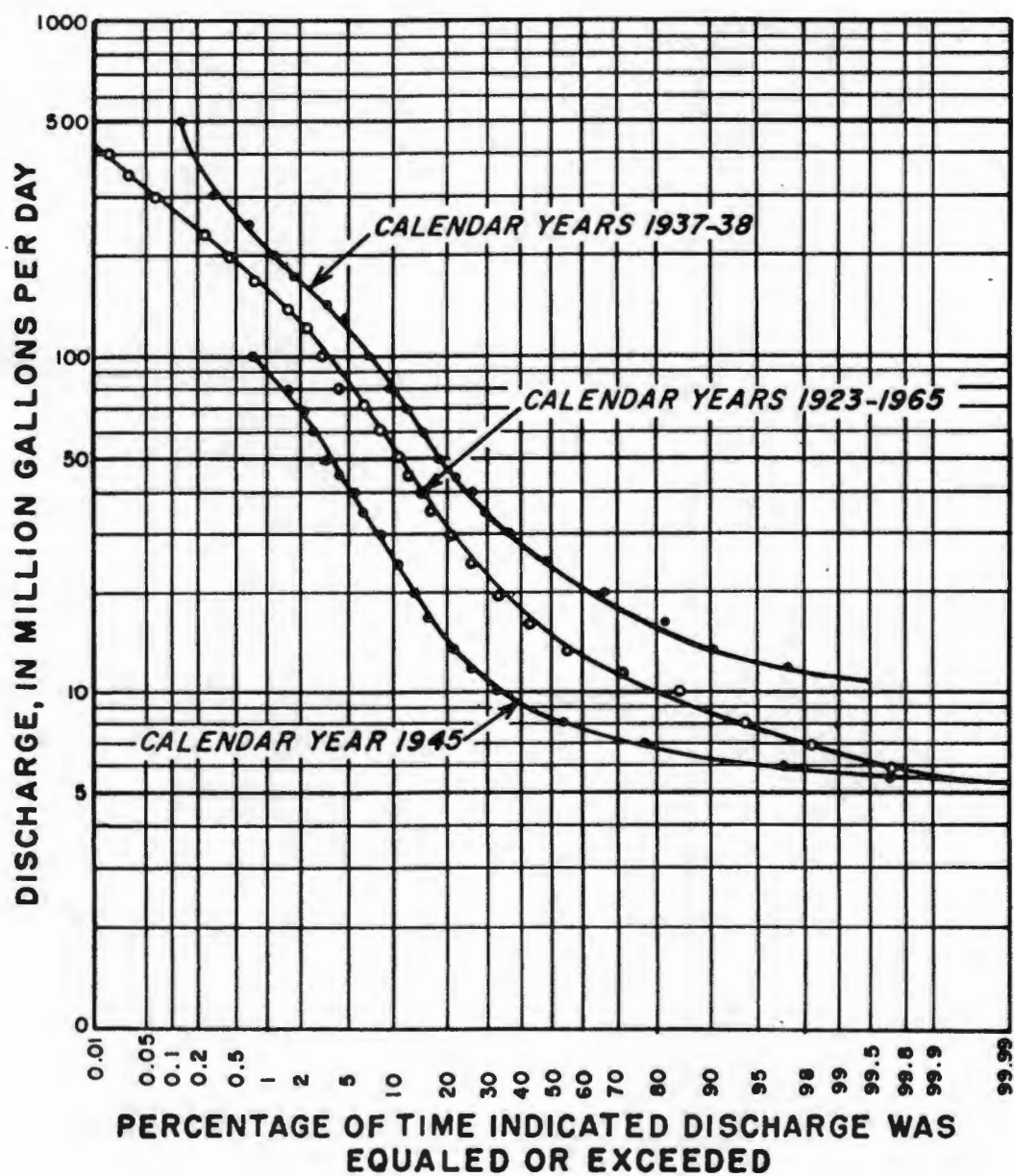


Figure 8. FLOW-DURATION CURVES FOR HONOKOHAU STREAM

intervals of various degrees of low flow were computed and curves were plotted (fig. 9). Applying these curves, mean daily flow can be expected to average as low as 10 mgd for a one-day period every year, for a 7-day period twice in 3 years, for a 14-day period once every 2 years, and for a 30-day period once in 3 years. A curve showing magnitude and frequency of floods at the site is given in figure 10.

Honolua, Honokahua, and Kahana Streams. These streams, in the northwestern sector of West Maui, are perennial in their upper reaches but are normally dry below 800 feet because their valleys have not been cut down deeply enough. An intake on Honolua Stream supplies about one-fourth million gallons per day to Honokohau ditch in dry weather but frequently goes dry. A diversion ditch from Kahana Stream has been abandoned because the stream is dry at the diversion point except during rain.

Honokowai Stream. Honokowai Stream is formed by the confluence of Amalu and Kapaloa Streams. Kapaloa, the southern branch, is longer and deeper and contributes most of the flow of Honokowai Stream. Measurements made in March 1967 indicate that more than 50 percent of the flow diverted by Honokowai ditch from Honokowai Stream during dry periods is water developed in tunnel T-20A in Kapaloa Valley (See table 6).

Kahoma and Kanaha Streams. Although Kahoma is one of the three drainages that begin at Puu Kukui, it has not been as deeply eroded as the other two, Honokohau and Iao, and its base flow is not as large as theirs.

Measurements made in June 1967 (table 6) indicate that in dry weather about 80 percent of the flow entering Kahoma ditch discharges from a development tunnel (T-18). Because the intake of the ditch, at altitude 1,930 feet is well within the dike zone, additional water enters the stream from ground-water seepage below the intake and is diverted farther downstream.

Kanaha is the southernmost of the long, narrow valleys. No development tunnels have been drilled in this valley. Records obtained for the periods 1916-24 and 1926-32 indicate

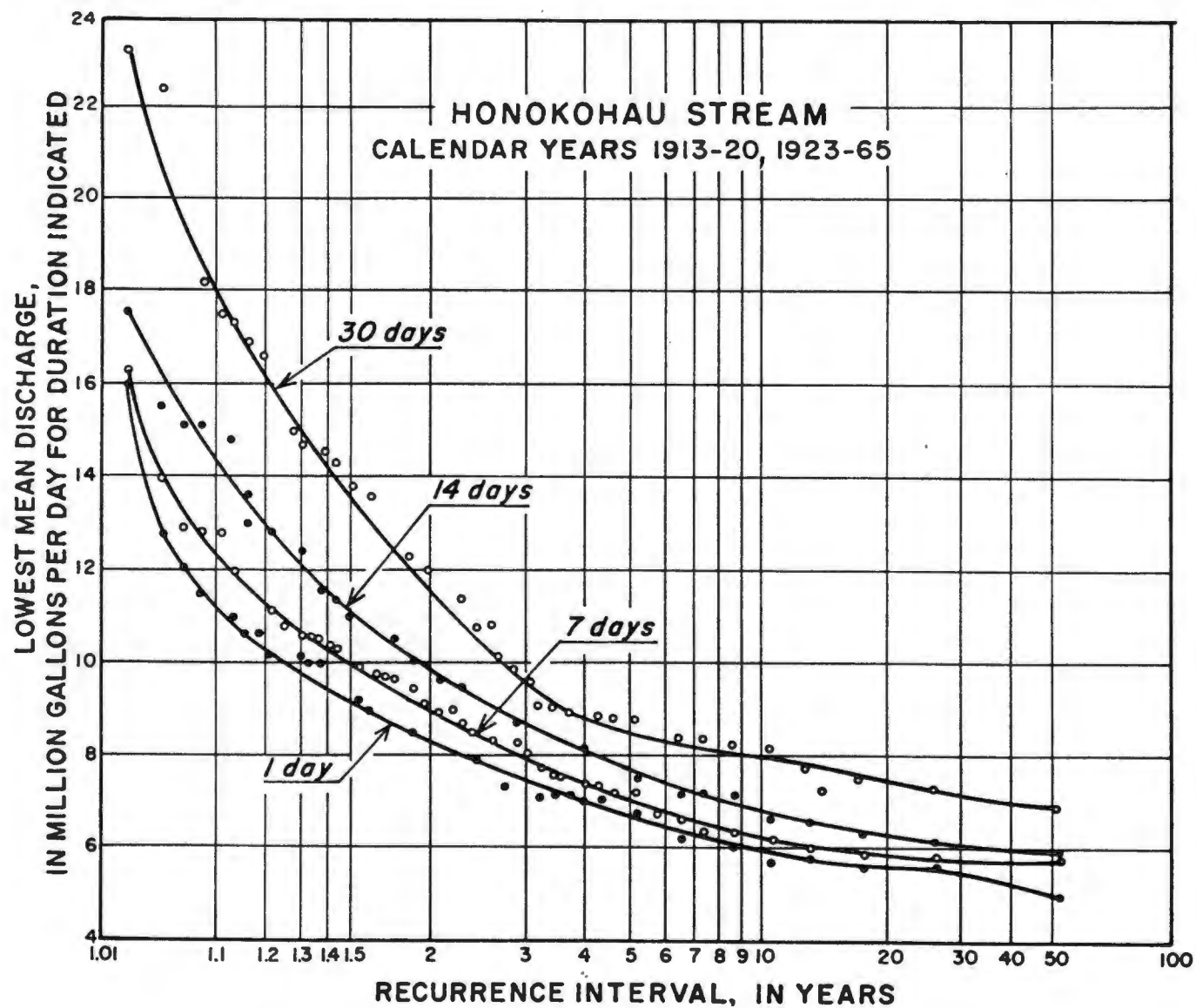


Figure 9. LOW-FLOW FREQUENCY CURVES FOR HONOKOHAU STREAM

Table 6. SELECTED STREAMFLOW MEASUREMENTS MADE
DURING PRESENT INVESTIGATION

Date	Name of stream	Altitude (ft)	Dis- charge (mgd)	Location
6-22-67	Honolua	1,600	0.213	150 feet down- stream from waterfall.
"	"	1,340	.245	Above tributary from right bank.
"	"	1,090	.284	
"	"	870	.232	At diversion point.
3-3-67	Kapaloa	1,710	.386	Above tunnel T-20.
"	Tunnel T-20A	1,700	1.76	
"	Amalu	1,580	.56	At diversion point.
"	Honokowai ditch	1,550	3.29	At gaging stations.
6-21-67	Kahoma development tunnel (T-18)	1,980	1.85	
"	Kahoma	1,930	2.29	At diversion point.
"	Kanaha	1,140	2.29	100 feet up- stream from intake.
2-28-67	Launiupoko	1,420	.67	Upstream from T-15.
"	Development tunnel T-15	1,420	.064	
"	Launiupoko	1,280	.95	At diversion point.
6-20-67	Olowalu	900	3.21	
"	"	540	3.76	"
6-23-67	Ukumehame	400	3.42	
"	"	240	3.04	At diversion point.

Development of Water Resources

History of Development. The early Hawaiians first developed water resources in Lahaina when they diverted streamflow for use in upland taro patches in some of the major stream valleys. Taro fields were also maintained in the lower reaches of perennial streams such as Honokohau, where a water right of 1 mgd is still observed. Drinking water was sometimes obtained from coastal springs or from shallow wells dug near coastal springs (Stearns, 1942, p. 127). Development by the early Hawaiians probably had little effect upon the hydrology of the Lahaina area.

By 1904 streamflow from Honokohau Valley in subarea A was being diverted into the newly completed Honokohau (Honolua) ditch and exported 13 miles to fields in subarea B. In 1913 improvements to the ditch increased the flow exported to subarea B (Pioneer Mill Co. annual report, 1913, p. 10).

The first tunnels for the development of high-level ground water were constructed during 1900-10. Successful tunnels appreciably increased the base flow of streams. Tunnels are shown in figure 6, and pertinent data are summarized in Stearns (1942, p. 213) and in table 7.

Pumping of irrigation water from the basal lens through drilled wells and Maui-type shafts began in 1883 (McCandless, 1936, p. 72), and four major pumping stations and associated shafts and wells were constructed in 1897. In the ensuing years use of ground water for irrigation increased as additional wells and shafts were constructed. Development of ground water for domestic use has recently become increasingly important. Tourism, with its resulting population expansion, has become a major factor in the area's economy. Data on all wells drilled in the area before 1941 were summarized by Stearns (1942, p. 216-219), and data on wells drilled since 1941 are given in table 8 of this report. Location of all wells and shafts are shown in figure 6.

Table 7. DEVELOPMENT-TUNNEL DISCHARGE

Subarea	Tunnels*	Daily flow** (mgd)	Period of record
A	22	a 1.81	1926-41
	21	a 2.25	"
B	20A	b 1.76	1967
	20B	b .58	"
	18	c 1.9	1940
	16	c 2.0	"
C	14-1	b .01	1967
	13	c .1	1940
Total flow		10.41	
Water that would normally appear in the channel down- stream from the intake#		3.8	
Total salvaged water		6.6	

* See figure 6.

**Daily flows from (a) unpublished Maui Pineapple Co. records, (b) unpublished Geological Survey records, and (c) Stearns (1942).

Stearns, 1942, p. 199.

Table 8. RAINFALL IN SUBAREAS OF LAHAINA DISTRICT

Subarea	High-level area (mgd)	Rainfall Basal Area		Total (mgd)	Subarea Total (mgd)
		Cropland (mgd)	Non- cropland (mgd)		
A	80	10	43	53	133
B	104	17	11	28	132
C	63	1	11	12	75
Total	247	28	65	93	340

Table 9. ESTIMATE OF RAINFALL & EVAPOTRANSPIRATION ON CROPLAND

Subarea	Cropland (1966)		Crop evapo- transpiration*		Rainfall on cropland	
	Cane (acres)	Pine- apple (acres)	Cane (mgd)	Pine- apple (mgd)	Cane (mgd)	Pine- apple (mgd)
A	0	3,000	0	5.4	--	10.5
B	8,545	1,000	53.4	1.8	14.0	2.8
C	853	0	5.3	0	0.9	--

*Assuming average annual evapotranspiration of 7 acre-feet per acre (.006251 mgd per acre) for cane and 2 acre-feet per acre (.00179 mgd per acre) for pineapple.

Pineapple is also grown in the Lahaina area. Pineapple growing on a commercial scale was begun on 20 acres of land in the Lahaina area in 1912. By 1920 field operations had become sufficiently extensive to justify a cannery at Mala (Baldwin, 1938, p. 16-17). At the present time (1967) pineapple is raised on about 4,000 acres in subarea A and the northern part of subarea B (fig. 6).

Effects of Development on Basal-Water Body. Development of water has affected the basal-water body in different ways in different areas. Delineation of the District into subareas A, B, and C (fig. 6) permits a meaningful description of the effects by defining areas where types and magnitudes of stress are similar. In general, where development causes inflow to exceed outflow, for example, by salvaging water that would otherwise be wasted to sea and introducing it as recharge, the basal lens thickens and water freshens. Where development causes outflow to exceed inflow, water is taken from storage and the lens thins, resulting in a concurrent salinization of the water. This is the situation in subarea A, from which water is exported to subareas B and C.

Cultivation of sugar cane results in an increase in evapotranspiration. The evapotranspiration rate for cane in the Lahaina area is approximately 7 acre-feet per acre per year or .00625 mgd per acre (letter from H. Tripple, Pioneer Mill Co.). The native vegetation replaced by the cane received its total water requirement from soil moisture derived from rainfall and, therefore, the water evaporated and transpired never exceeded rainfall, which averages about 2 feet per year. Thus, an increase in average annual evapotranspiration of at least 5 acre-feet per acre has resulted from the change from native vegetation to cane. Pineapple needs much less water than cane and does not require irrigation, although a small amount of water is applied to fields for mulching and to convey fertilizers and insecticides to the growing plants. Average annual evapotranspiration for pineapple planted at the standard density

of 4.3 plants per square meter is about 2 acre-feet per acre for a 6-month-old plant with a leaf area index of 2.6 (Ekern, 1965, p. 738). Annual rainfall on areas planted in pineapple in the Lahaina area averages about 4 acre-feet per acre. Thus, evapotranspiration is unchanged when native vegetation is replaced with pineapple.

The distribution of rainfall by subarea is given in table 8 and the relation of rainfall and evapotranspiration on the subareas are summarized in table 9.

The most significant effect upon the hydrologic system has resulted from plantation farming, particularly the cultivation of sugar cane. Before about 1850 cane was grown without irrigation and often consisted only of native cane growing around the edges of flooded taro fields (Wadsworth, 1933, p. 139). Between 1850 and 1870, larger tracts of sugar cane were developed. Because the water requirements of cane exceed local rainfall in this area, these tracts probably were located on the flood plains of the larger streams, where freshets and some high to medium flows could be utilized by constructing modest irrigation works. Between 1890 and 1900, cane acreage was apparently further expanded, necessitating extensive development of surface water and ground water for irrigation (O'Shaughnessy, 1909, p. 399). Expansion continued, and sugar cane acreage, which was about 5,000 acres in 1901, increased to approximately 8,000 acres by 1914. Acreage was about 9,000 acres in 1920 and has remained stable since, although sugar yields have risen because of more efficient methods of cultivating, irrigating, and milling. In 1966, about 9,400 acres of cane fields were cultivated, all in subareas B and C, as shown in figure 6.

Irrigation water for sugar cane is mainly obtained in four ways: (1) diversion of streamflow within subareas B and C, (2) diversion of streamflow from subarea A to subarea B through Honokohau ditch, (3) diversion of high-level ground water by tunnels, and (4) pumping of ground water directly from

the basal reservoir in subareas B and C. Data for each of the four are summarized in tables 7, 10, and 11.

Some of the floodflow that originally wasted to sea in subareas B and C is salvaged for cane irrigation, and part of it percolates to the basal reservoir. On the other hand, where under original conditions most of the base flow and medium flow of streams probably percolated directly to the basal lens, nearly all the base flow and much of the medium flow are probably now intercepted and transmitted to the cane fields, where much of it evaporates and is transpired. The quantity of salvaged floodflow recharging the basal lens in subarea B is probably not large enough to offset the larger discharge through increased evapotranspiration, and a net loss to the basal-water body results.

This loss is compensated by importing Honokohau streamflow from subarea A, increasing total inflow to subarea B by more than 100 percent (table 10). Nearly all this imported water is applied to cane fields, and much of it percolates to the basal lens. The increased recharge to the basal lens more than compensates for losses due to higher evapotranspiration and interception of local streamflow and results in a surplus in subarea B. In subarea A, where much of the runoff from Honokohau Valley is exported to subarea B, there is a net deficit of inflow to outflow.

Additional water for irrigation has been developed by tunneling in the upper valleys. A large part of the high-level ground water probably enters the basal reservoir by underflow. The tunnels divert some of this high-level ground water into the stream channels, thereby causing a net increase of the base flow of streams in the Lahaina area by about 6.6 mgd (table 7).

The most direct stress on the basal-water body is imposed by pumping. Most of the pumping is from wells in subarea B, with a smaller amount from wells in subarea C. Pumpage data are summarized in table 11 and monthly pumpage for the Lahaina area is shown in figure 11.

Table 10. DISTRIBUTION OF STREAMFLOW BY
DIVERSIONS ON CROPLAND BY SUBAREAS

Subarea Symbol	Area* (sq mi)	Stream valley or source	Average annual surface- water diversions**	
			Developed# (mgd)	Applied### (mgd)
A	10.5	Honokohau	24.7	2
		Honolulu		
		Subtotal	24.7	2
B	20.5	Mahinahina weir	--	22.5
		Honokowai	5.7	
		Kahoma	5.2	
		Kanaha	1.7	16.0
		Kauaula	5.6	
		Launiupoko	0.7	
		Subtotal	18.9	38.5
C	8.6	Olowalu	5.0	
		Ukumehame	4.3	7.0
		Subtotal	9.3	7.0

*Includes area of high-level water only.

**Includes water from high-level development tunnels.
Data from Pioneer Mill Co. records.

#Water diverted at intakes except for figure given for
Honokohau which represents water passing Mahinahina from
subarea A to subarea B.

###Water delivered to fields within the subarea.

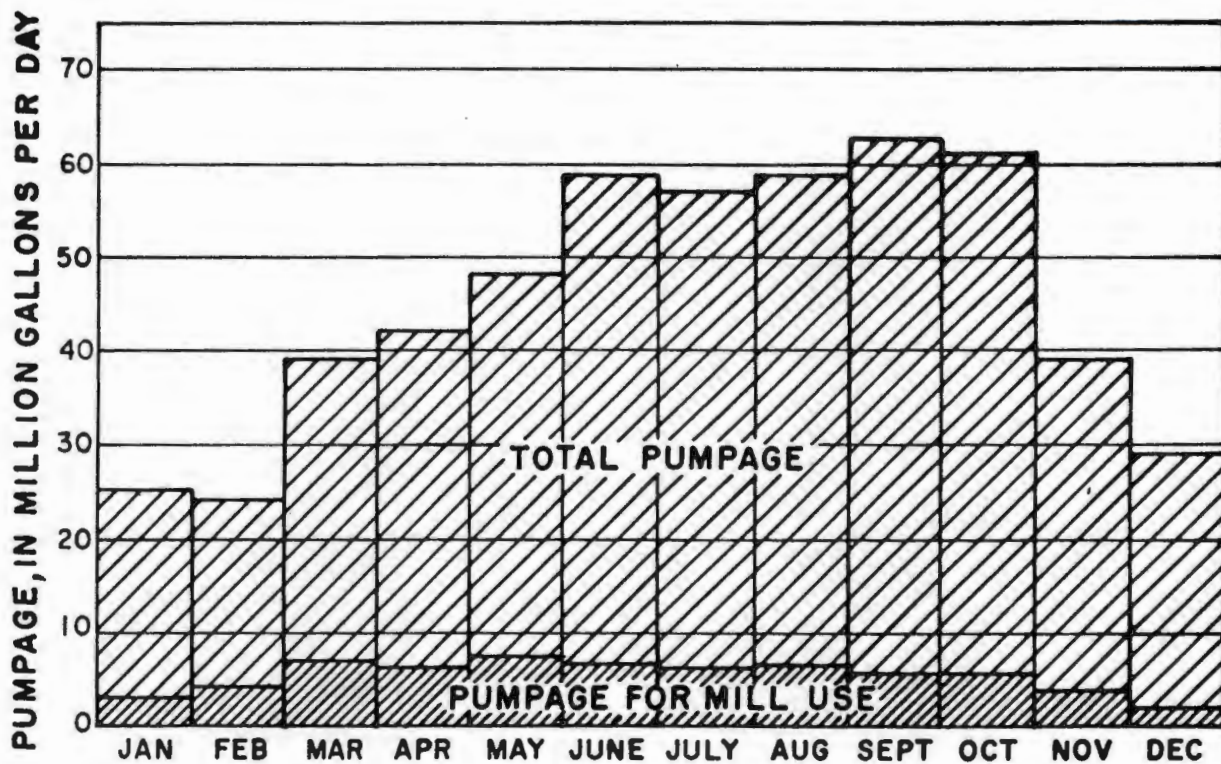


Figure 11. GRAPH SHOWING AVERAGE MONTHLY PUMPAGE FROM SHAFTS IN LAHAINA AREA

Table 11. AVERAGE PUMPAGE FOR IRRIGATION AND MILL USE AND WASTE BY SUB-AREA (1955-66)

Subarea	Average pumpage (mgd)
A	0
B	42.24
C	3.33
	<hr/>
Total	45.57
	<hr/>
Total applied to fields	40.09

There has apparently not been a widespread deterioration of water quality in the basal lens due to pumping. This is demonstrated by graphs in figures 12-15 in which the relations between maximum annual chloride concentration and annual pumpage from selected shafts are shown. Wide local variations in salinity over short time periods are related to pumping rates. Increases in chloride concentration of basal ground water are short-term effects which can usually be reversed by lowering pumping rates.

Chloride content in subareas B and C has remained roughly the same throughout most of the period of development, and local short-term changes owing to pumping have been reversed either by reducing pumping rates or by relocating wells. The areas of high chloride content today probably were similarly high under predevelopment conditions. Water levels and chloride concentrations in irrigation wells for the period 1940 to 1966 are listed in table 12.

Some long-term deterioration of basal ground-water quality may be occurring in subarea B. Recharged irrigation water containing salts from fertilizers may be concentrating in the upper part of the lens, remaining out of the main flow paths of fresh ground water moving seaward. Quality deterioration in the upper part of the lens is indicated by the plot of chloride concentration against time during a test of well 291 (fig. 16).

Water use for agriculture is summarized by subareas in table 13, and that for domestic purposes, in table 14. As the economy of the District becomes increasingly tourist oriented, population will increase and more and more water will be required for domestic purposes.

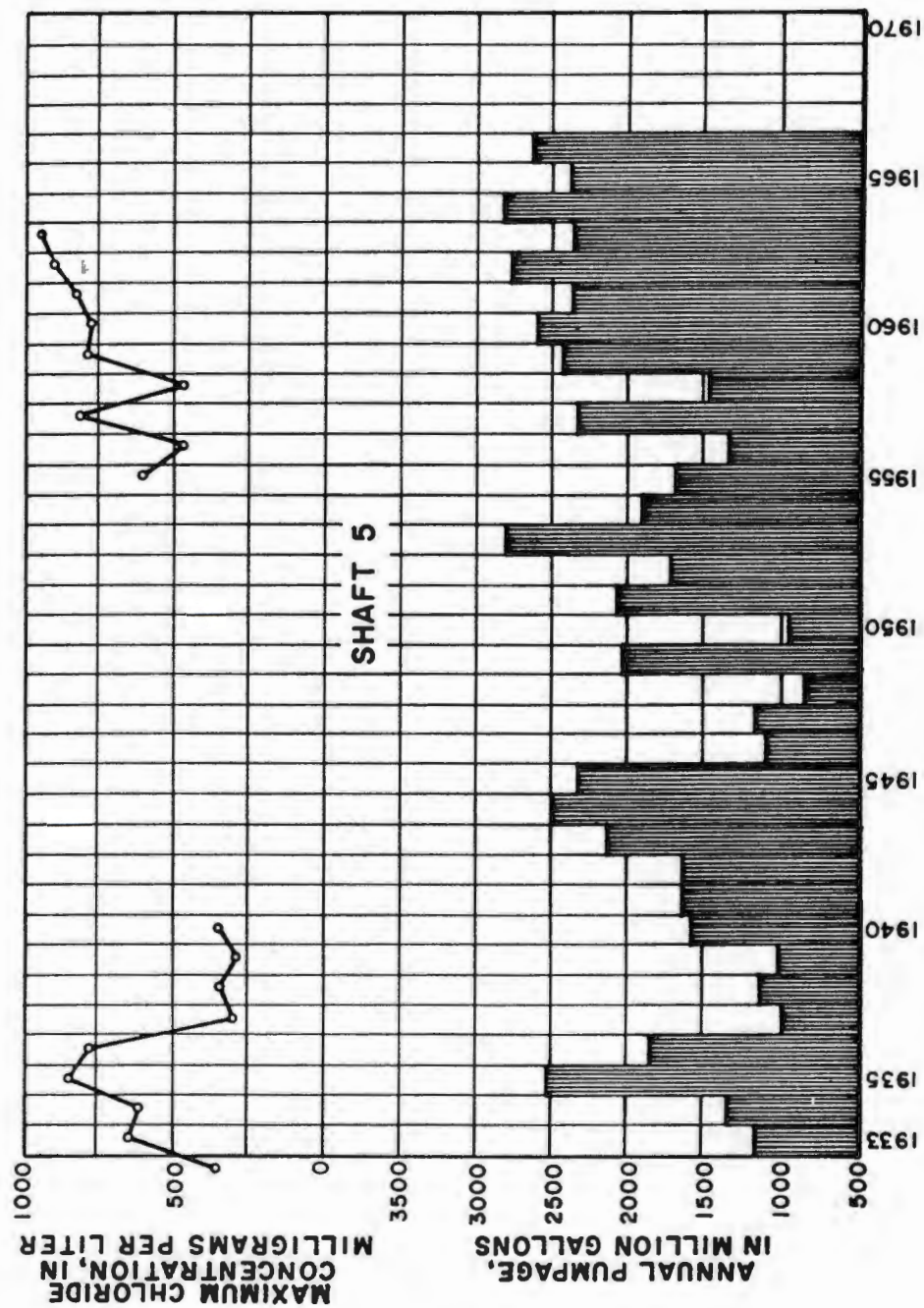


Figure 12. GRAPH SHOWING RELATION OF PUMPAGE AND CHLORIDE CONTENT

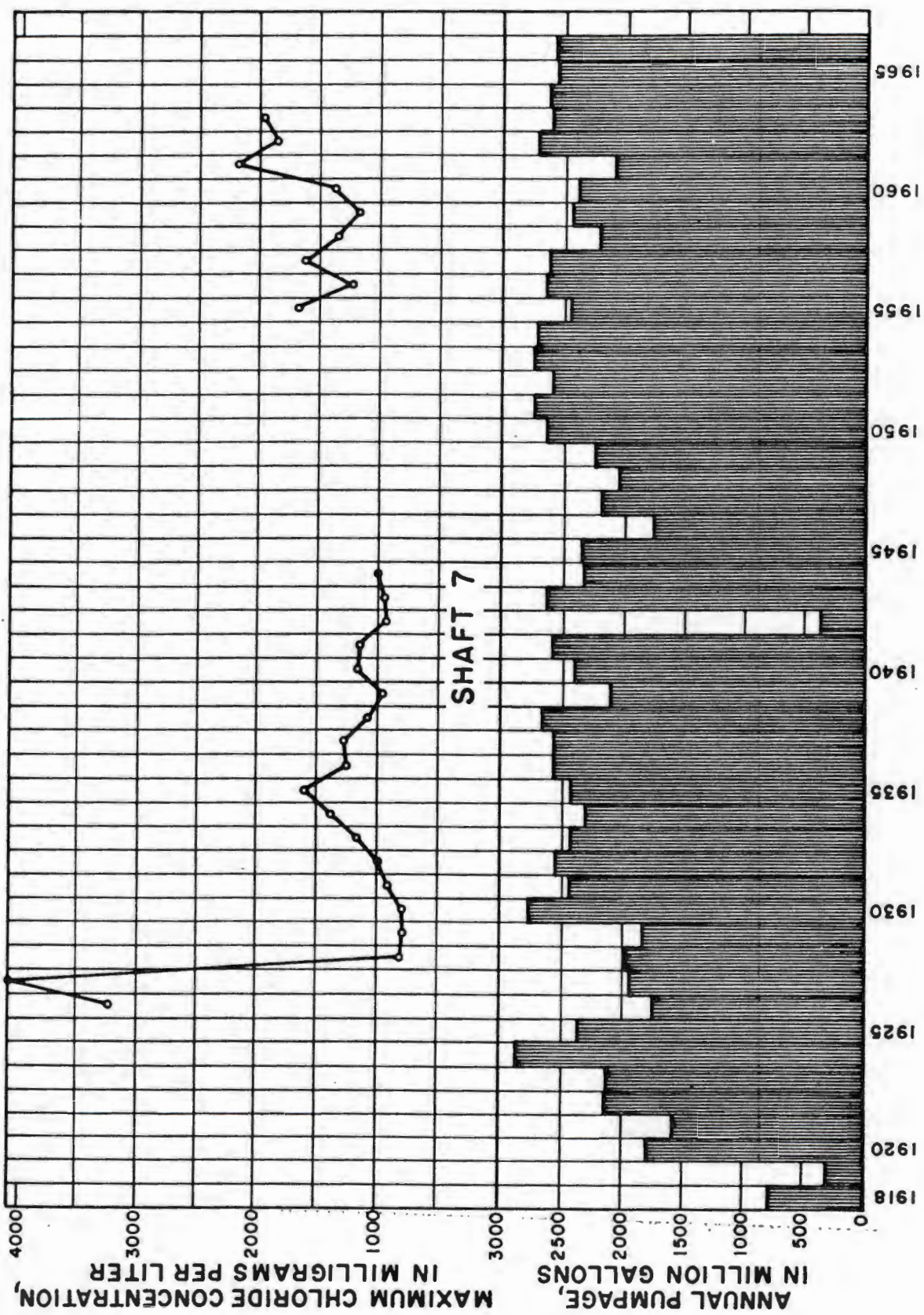


Figure 13. GRAPH SHOWING RELATION OF PUMPAGE AND CHLORIDE CONTENT

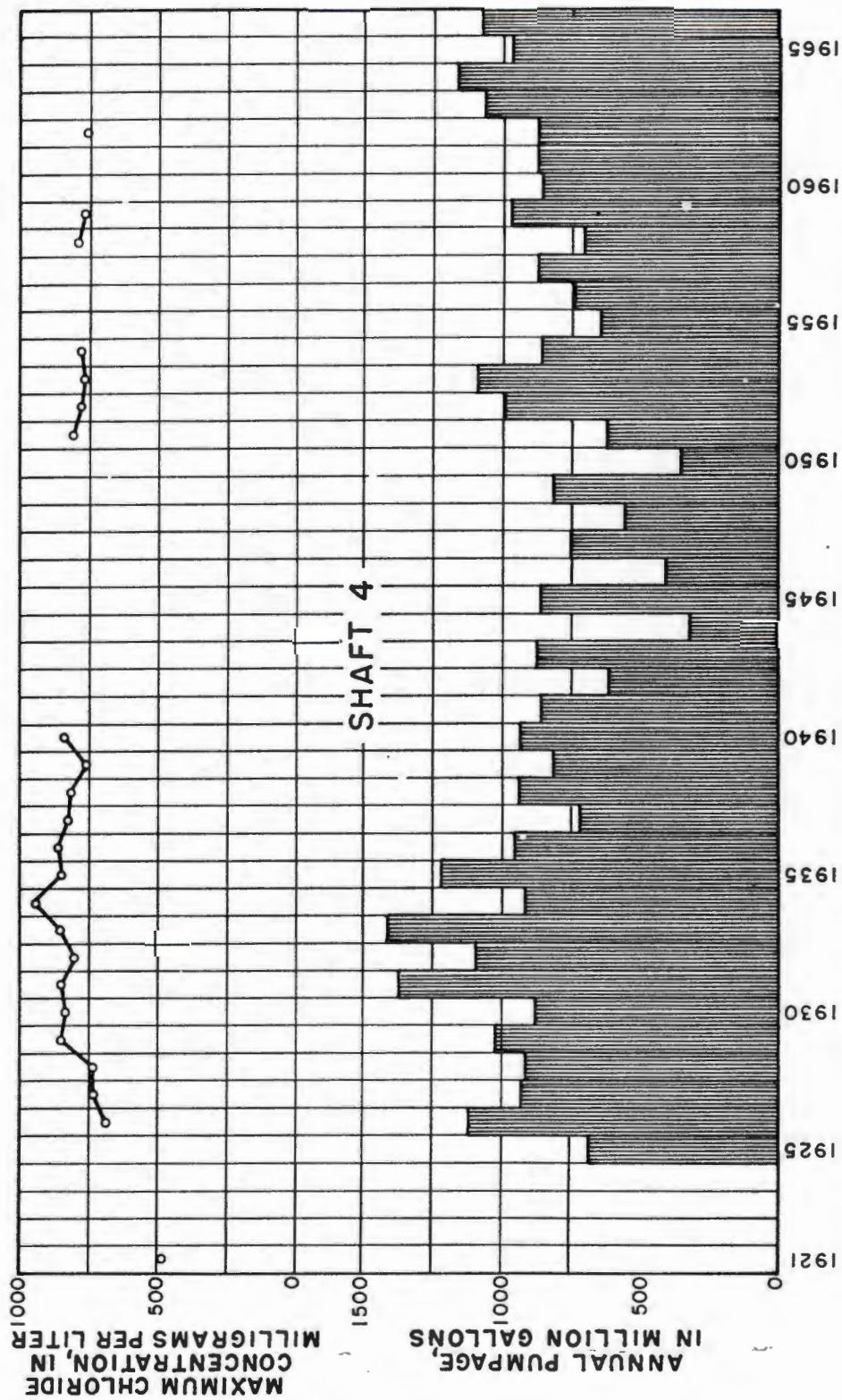


Figure 14. GRAPH SHOWING RELATION OF PUMPAGE AND CHLORIDE CONTENT

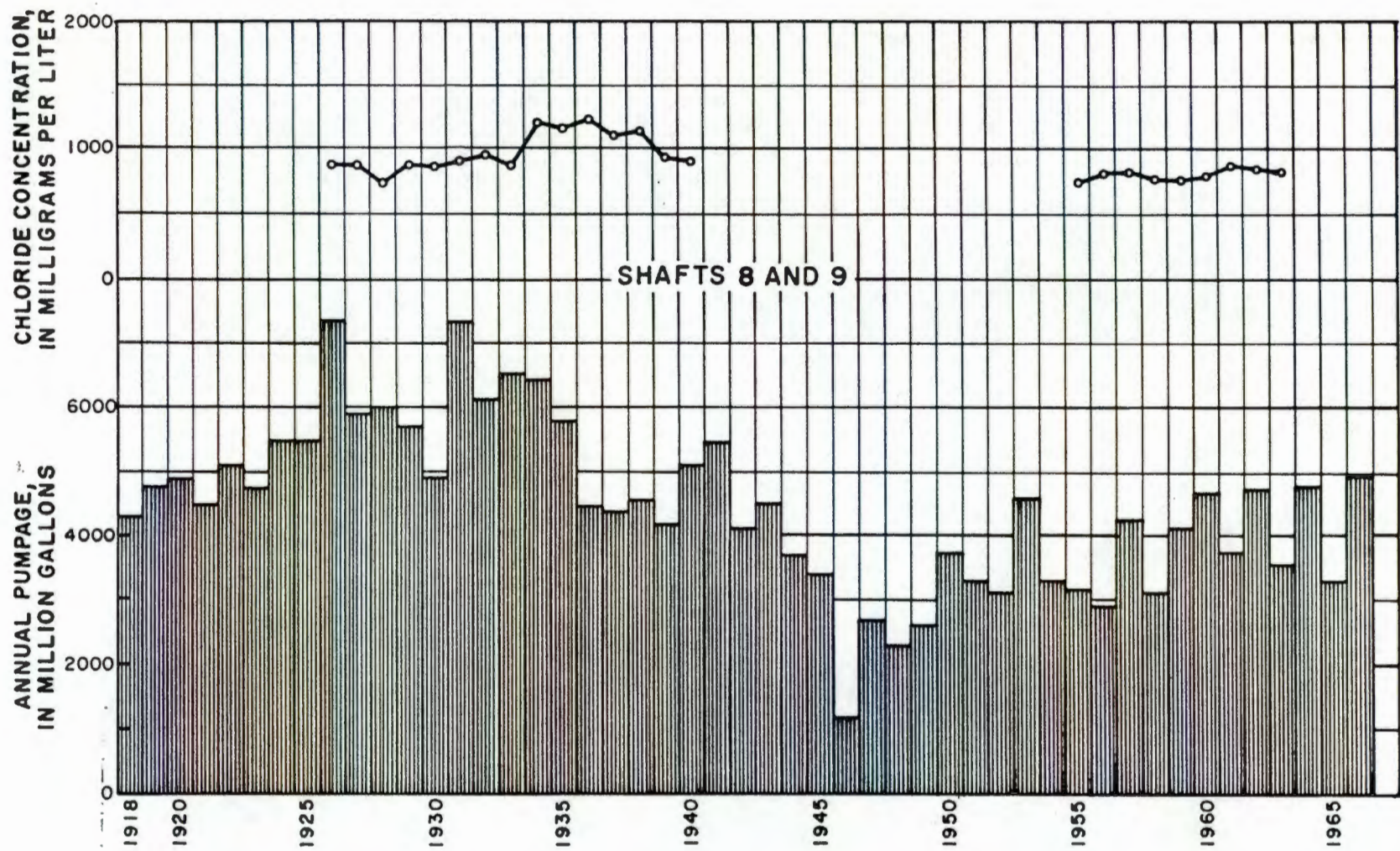


Figure 15. GRAPH SHOWING RELATION OF PUMPAGE AND CHLORIDE CONTENT OF SHAFTS 8 AND 9 (Pumpage of the two shafts are shown as a total and the chloride content is representative of shaft 9.)

Table 12. WATER LEVELS AND CHLORIDE CONCENTRATIONS IN SHAFTS

Shaft No.	Date	Water level in feet above msl	Date	Chloride (mg/l)	Records available through 1963*		
					P	Cl	WL
1	1940	2.0	--	--			
	1940	2.0	12-13-63	1,089	x	x	
			7-20-60	216			
3	12-31-49	1.4	8-30-63	1,076	x	x	x
	12-31-48	2.8	3-30-62	224			
4	1940	1.5	7-28-61	927	x	x	
			2-19-57	108			
5	1935	1.8	1- 4-63	952	x	x	x
	12-31-48	3.6	6-21-58	83			
6	1940	1.5	7-30-57	715	x	x	
			4- 4-57	328			
7	12-31-63	2.45	10-20-61	2,183	x	x	x
	12-31-48	3.78	8-16-57	596			
8	1940	2.0	10- 6-61	1,463	x	x	
			2-19-57	208			
9	12-31-62	1.22	7-28-61	873	x	x	x
	13-31-48	2.98	3- 6-59	112			
10	12-31-62	2.54	12-14-62	1,030	x	x	x
			12-31-50	86			
	12-31-50	4.30	3-27-59	96			
11	1940	2.0	6-28-63	673	x	x	
			3-20-59	50			
12	12-31-43	4.27	6- 8-62	597	x	x	x
	12-31-50	6.75	2- 9-62	274			
36	--	--	10-12-62	931	x	x	
			1-16-57	54			

*P = pumpage; Cl = chloride; WL = continuous water levels.

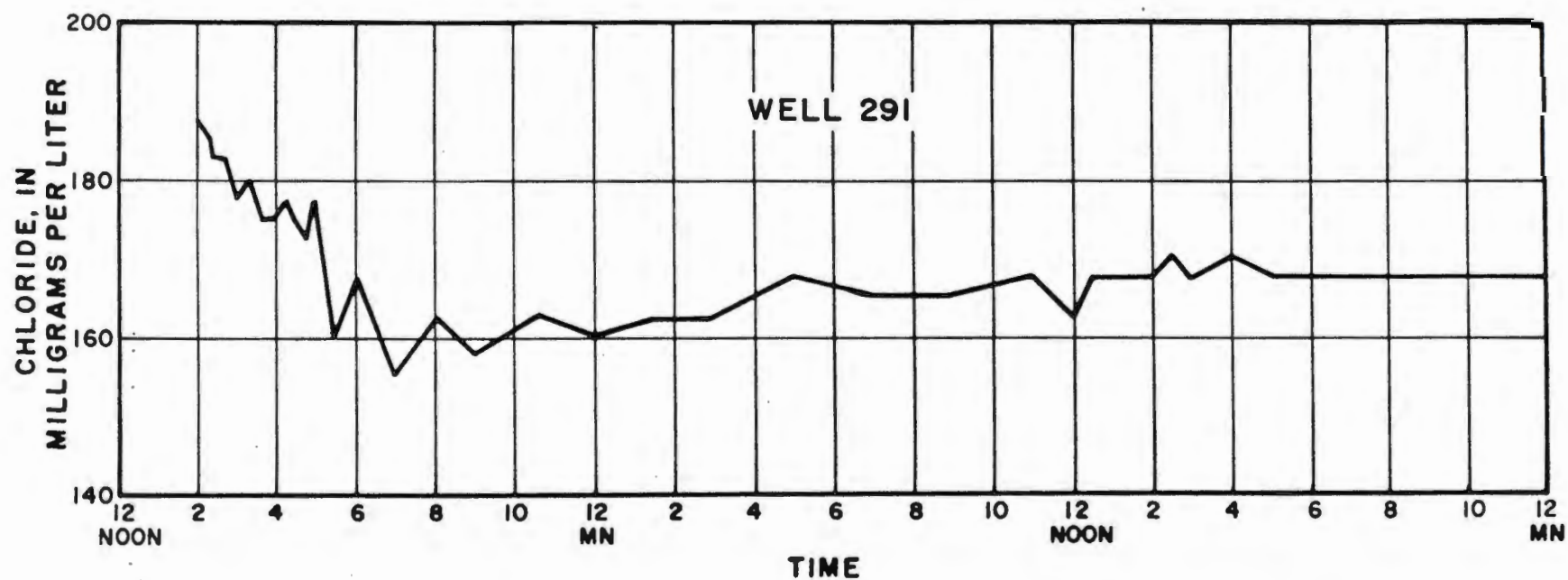


Figure 16. CHLORIDE CONTENT OF WATER FROM WELL 291 DURING PUMPING TEST

Table 13. DISTRIBUTION OF DEVELOPED WATER FOR AGRICULTURAL USE BY SUBAREAS

Subarea	Surface-water yield			Pumpage or ground water applied (mgd)	Rainfall on cropland (mgd)	Total water applied on cropland (mgd)	Crop use (mgd)
	Total diver- sion (mgd)	Imported (+) exported (-) (mgd)	Seepage or applied (mgd)				
A	28	(-) 25	3	0	10	13	6
B	19	(+) 22	38	37	17	92	55
C	9	0	7	3	1	11	5

Table 14. DOMESTIC USE OF WATER, 1967

Subarea	System	Domestic use, 1967* (Thousands of gal per day)
A	Honokohau	0.7
	Honokahua	--
	Alaeloa-Kahana	55
	Total for subarea A	56
B	Honokowai	40
	Kaanapali-Puu Kolii	925
	Lahaina	500
	Lahainaluna	60
	Total for subarea B	1,525
C	Olowalu-Ukumehame	--
	Total for subarea C	--
	Total for area	1,600

*Estimates based on Division of Water and Land Development (1961, p. 25) Rept. R21 and unpublished data from Pioneer Mill Co., Ltd.

NEED FOR FURTHER INVESTIGATIONS

More detailed investigations are needed to determine the quantity and distribution of water throughout the area and where and how additional water may be most effectively developed, particularly for domestic use.

Exploration for additional ground water should include dike mapping and test drilling. Detailed dike mapping in Honokohau, Honokowai, Kahoma, and Kauaula Valleys would help in estimating the amount of high-level water that could be salvaged by bulkheading tunnels. The feasibility of developing water by pumping from dike compartments could be investigated by test drilling near the edge of the high-level water body in Kahoma, Kanaha, and Kauaula Valleys. Pumping of high-level water could result in salvaging water of good quality before it enters the basal lens.

Test holes drilled in the north end of the district, perhaps near or in Honokohau Valley, downstream from the intake of Honokohau ditch, would provide valuable information about the ground water that is probably escaping to sea in considerable quantity.

The present network of gaging stations has produced data sufficient for a fairly reliable appraisal of the normal, dry weather, surface-water supply. The data, however, are not adequate to define the total flow of the streams, and more flood-flow information is needed. Recent frequent flooding of some of the resort developments, especially in the Mahinahina-Napili area, points out the need for more flood frequency-magnitude information. An expansion of the network is therefore desirable--beginning with the installation of recording stations on the lower reaches of Honokowai and Honolua Streams. Flood-inundation studies would be desirable at sites where resort developments may be contemplated, such as near the Honolua and Honokahua Bays.

REFERENCES CITED

- Avias, Jacques, and others, 1956, Zone des Hawaï, Chap. 2 in Océanie proprement dite, Fasc. 2 of Océanie v. 6 of International Geological Congress, Strat. Comm., Lexique stratigraphique international: Paris, Centre Natl. Recherche Sci., p. 71-143.
- Baldwin, W.A., 1938, A brief history and commentary on the pineapple industry of Hawaii, Wailuku, Maui, Territory of Hawaii: Maui Publishing Co., 32 p.
- Division of Water and Land Development, 1963, Improvements to county water systems, Lahaina District, Maui: Rept. R21, 38 p., 13 pl.
- Ekern, P.C., 1965, Evapotranspiration of pineapple in Hawaii: Plant Physiology, v. 40, no. 4, p. 736-739.
- Malahoff, Alexander, and Woollard, G.P., 1966, Geologic implications of magnetic surveys over the Hawaiian Islands: Pacific Science, vol. 20, no. 3, p. 265-311.
- McCandless, J.S., 1936, Development of artesian well water in the Hawaiian Islands, 1880-1936; Honolulu, Hawaii: Advertiser Publishing Co., Ltd., 79 p.
- O'Shaughnessy, M.M., 1909, Irrigation works in the Hawaiian Islands: Engineering News, vol. 61, no. 15, p. 399-403.
- Pioneer Mill Co., Ltd., 1913, Annual report.
- _____, 1922, Annual report.
- Stearns, H.T., and Macdonald, G.A., 1942, Geology and groundwater resources of the island of Maui, Hawaii: Hawaii Div. Hydrography Bull. 7, 344 p., 44 pl.
- Takasaki, K.J., Hirashima, G.T., and Lubke, E.R., Water resources of windward Oahu, Hawaii: U.S. Geol. Survey Water-Supply Paper 1894, (in press).
- Wadsworth, H.A., 1933, A historical summary of irrigation in Hawaii: Planters Record, vol. 37, no. 3, p. 124-162.
- U.S. Geological Survey, 1961, Compilation of records of surface waters of Hawaii through June 1950: U.S. Geol. Survey Water-Supply Paper 1319, 316 p.